ULTRASONIC MODELING OF LUNAR APPROACH OF THE LUNAR EXCURSION MODULE*

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ABSTRACT

This report covers the ultrasonic system modeling of the LEM system and the lunar surface for three possible landing areas, P-6, P-8 and P-11 selected from Orbiter II data, as agreed to between Mr. R. Broderick and Pat Rozas of NASA - Manned Spacecraft Center, and Dr. H. S. Hayre of the University of Houston.

Modeling Factors for Ultrasonic
Simulation of LEM Landing Trajectory

The modeling scheme presented in this report is based on complex nonlinear ultrasonic scaling of radar system parameters. In short, this means distances, antenna velocities and frequencies may be selected independently in accordance with the size of the ultrasonic simulation facility, whereas other parameters such as doppler frequency, wavelength, time delay, etc., are then specified in terms of the previously specified parameters.

The transducers to be used in the simulation are piezoelectric type and are designed to operate around a center frequency on 1 MHZ. The velocity beams of the LEM radar operate at 10.5 GHZ. The ratio of radar frequency to the ultrasonic frequency of one megacycle/second gives the frequency scale factor, f_x. This, and other factors are listed in Table I.

In order to simulate the large lunar distances properly, two or three model surfaces are being prepared for each site as discussed in the later sections of this report. Each model surface will be 10-12 feet in length and 4 feet in width. Each model surface represents the area traversed by radar beams during different sections of the LEM trajectory. One of the models represents the lunar surface within half of the probability ellipse for that site while the others

TABLE I

SCALE FACTORS USED IN LUNAR SIMULATION

PARAMETER	IN AIR	IN WATER	SCALE FACTOR
Frequency	10.5 GHZ	1 MHZ	f 10.5 X 10^3
Distance	12950 Ft. 164050 Ft.	12 Ft. 24 Ft.	rs_1=1080 rs_2=6850
Velocity of Propagation	3 X 10^8 m/sec.	1.5 X 10^3 m/sec.	C_s=2 X 10^5

will represent the lunar surface along the approach to the ellipse. The probability ellipses are 7.9 KM along the East-West direction. Therefore, the distance scale factor r_s, for this portion of the lunar surface is the ratio of 7.9 km/2 = 12,950 feet to 12 feet, listed in Table I.

When the LEM is at an altitude of 25,000 feet above the lunar surface, the distance to the landing site is 177,000 feet. After scaling the portion of the surface within the landing ellipse, there remains 164,050 feet of the total approach path. This remaining distance is scaled to 24 feet which is equivalent to two 12 foot models or one 12 foot model with double strip each to be traversed in the two consecutive runs. The distance scale factor along the approach is the ratio of 164,050 to 24. This produces the scale factor r_{s2}.

In addition to the frequency and distance scale factors, the scale factor for the velocity of propagation C_s is defined as the ratio of the velocity of light in air to the velocity of sound in water. Table I shows this and all other scale factors used in this study.

The primary consideration in selecting simulated antenna velocities are the maximum and minimum velocities which may be obtained by the primary (longitudinal) and secondary (cross) carriages of the acoustic facility used to position the transducers with respect to the simulated lunar surface. Simulation velocities are also limited by the size of the water tank.

The velocity scale factors were so chosen as to limit all simulated velocity variations to lie between the two extremes dictated by such physical limitations. Because three different component surface models are expected to be used for each site, three velocity scale factors, $V_{s_1} = 1.56 \times 10^3$ for the simulated ellipse area, $V_{s_2} = 6 \times 10^3$ for velocities at upper altitudes of the approach as shown in Table I.

These scale factors and the coordinate system shown in the diagram below were used to scale different LEM radar parameters such as distance, velocity, acceleration and (approximate) time measured from the starting point used as a reference are given in Table II. All unprimed parameters correspond to the landing radar while the primed ones indicate the scaled parameters.

Diagram of coordinates for parameters in Table II.

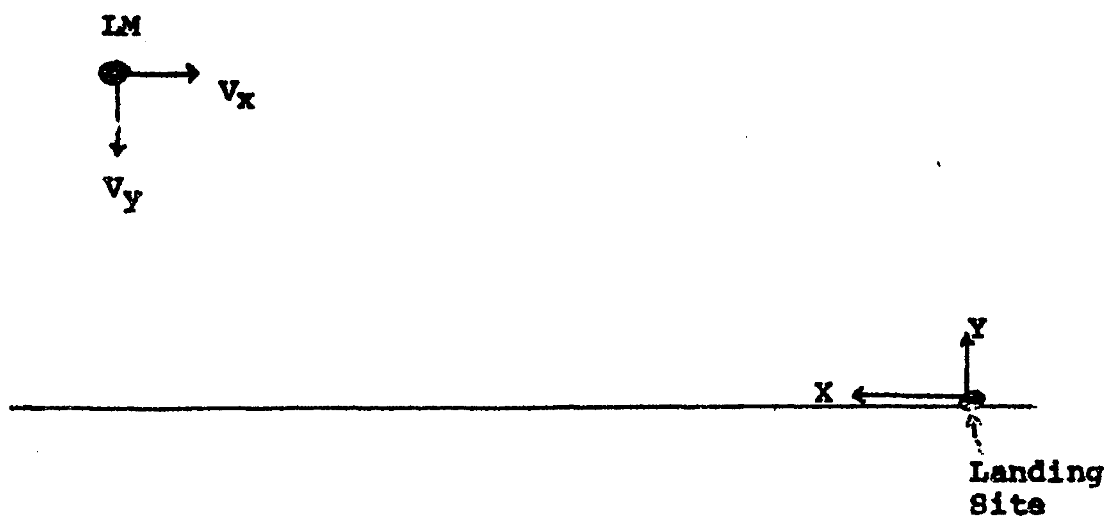


TABLE II

X FT.	X' FT.	Y FT.	Y' FT.	V_x FT/SEC	V'_x FT/SEC	V_y FT/SEC	V'_y FT/SEC	A'_x FT/SEC^2	A'_y FT/SEC^2	t' SEC
195	.181	200	.185	26.3	.0168	10.6	.0068	0.96×10^{-3}	3.06×10^{-4}	2.61
246	.228	220	.204	30.2	.0193	11.8	.0076	1.15×10^{-3}	3.17×10^{-4}	14.2
670	.620	373	.345	55.6	.0356	18.9	.0121	1.3×10^{-3}	2.83×10^{-4}	1.7
740	.685	400	.370	59.1	.0379	19.7	.0126	1.34×10^{-3}	3.31×10^{-4}	12.7
1380	1.280	600	.555	86.9	.0556	26.3	.0168	1.61×10^{-3}	3.54×10^{-4}	5.1
1710	1.584	700	.647	99.5	.0638	29.1	.0186	1.67×10^{-3}	3.66×10^{-4}	9.3
2430	2.250	900	.832	123.6	.0792	34.3	.0220	1.88×10^{-3}	3.82×10^{-4}	14.4
3870	3.580	1290	1.19	165.1	.106	42.9	.0275	2.02×10^{-3}	4.1×10^{-4}	14.4
5740	5.310	1760	1.63	210.8	.135	52.2	.0384	2.21×10^{-3}	4.6×10^{-4}	14.5
8100	7.500	2300	2.13	260.2	.167	62.6	.0401	2.28×10^{-3}	5.0×10^{-4}	14.7
11000	10.70	3000	2.78	312.7	.200	74.2	.0475	2.47×10^{-3}	5.3×10^{-4}	8.5
12950	12.00	3400	3.15	345.0	.221	81.0	.0520			
K FT.		K FT.								
12.95	0	3.4K	.496	345	.057	81.0	.0135	1.11×10^{-3}	2.78×10^{-4}	3.6
14.4	.212	3.8K	.555	367.7	.061	87.2	.0145	1.14×10^{-3}	2.84×10^{-4}	8.8
18.3	.782	4.8	.702	424.6	.071	101.9	.0170	1.07×10^{-3}	3.22×10^{-4}	8.4
22.8	1.44	5.87	.858	483.0	.080	118.5	.0197	1.28×10^{-3}	2.82×10^{-4}	3.9
25.0	1.76	6.5	.950	512.0	.085	125.0	.0208	$.7 \times 10^{-3}$	2.78×10^{-4}	7.2
27.9	2.18	7.15	1.04	542.0	.090	137.3	.0228	1.14×10^{-3}	4.0×10^{-4}	7.0
32.5	2.86	8.31	1.21	590.0	.098	154.0	.0256	1.1×10^{-3}	3.3×10^{-4}	1.82
33.7	3.04	8.622	1.26	602.0	.10	157.0	.0262	1.9×10^{-3}	$.63 \times 10^{-4}$	1.58
34.9	3.20	8.938	1.30	617.0	.103	158.0	.0263	1.04×10^{-3}	$-.52 \times 10^{-4}$	1.92
36.2	3.40	9.250	1.35	633.0	.105	155.6	.0262	1.6×10^{-3}	-1.5×10^{-4}	21.3
53.9	6.00	12.8	1.87	832.0	.139	138.0	.023	1.4×10^{-3}	-1.5×10^{-4}	20.0
75	9.07	15.8	2.31	1000	.167	120.0	.020	2.37×10^{-3}	-3.96×10^{-4}	2.53
78.3	9.50	16.2	2.37	1037	.173	114.0	.0190	2.77×10^{-3}	1.93×10^{-4}	8.30
88.5	11.04	17.3	2.53	1175	.196	124.0	.0206	1.67×10^{-3}	$.42 \times 10^{-4}$	4.8
95	12.00	17.95	2.62	1225	.204	125.0	.0208			101

MODEL 2 - RUN 2

X	X'	Y	Y'	V_x	V'_x	V_y	V'_y
95K	0	17.95K	2.62	1225	.1225	125	.0125
100K	.70	18.4K	2.69	1300	.13	130	.0130
107.5K	1.80	19.2	2.80	1396	.14	134	.0134
125K	4.40	20.8	3.04	1650	.165	141	.0141
150K	8.00	23.0	3.36	1820	.182	145	.0145
177K	12.00	25.0	3.65	2020	.202	147	.0147

A'_x	A'_y	ω_x	ω_y	α_x	α_y	t
		14.0	1.43			
1.36×10^{-3}	$.91 \times 10^{-4}$			16.3×10^{-3}	1.09×10^{-3}	5.5
		14.9	1.49			
1.23×10^{-3}	$.49 \times 10^{-4}$			14.8×10^{-3}	$.59 \times 10^{-3}$	8.1
		16.1	1.54			
1.47×10^{-3}	$.41 \times 10^{-4}$			17.6×10^{-3}	$.49 \times 10^{-3}$	17.0
		18.9	1.62			
$.82 \times 10^{-3}$	$.19 \times 10^{-4}$			9.8×10^{-3}	$.23 \times 10^{-3}$	20.8
		20.9	1.66			
$.96 \times 10^{-3}$	$.096 \times 10^{-4}$			11.5×10^{-3}	$.115 \times 10^{-3}$	20.8
		23.2	1.69			
						72

The doppler frequencies at all points have not as yet been determined. If V_1', V_2' and V_3' represent the velocities along the velocity beams and V_x', V_y' the horizontal and vertical components of velocity, then

$$V_3' = \Gamma_1 V_x' - \Gamma_2 V_y'$$

$$V_1' = \Gamma_3 V_x' + \Gamma_y V_y'$$

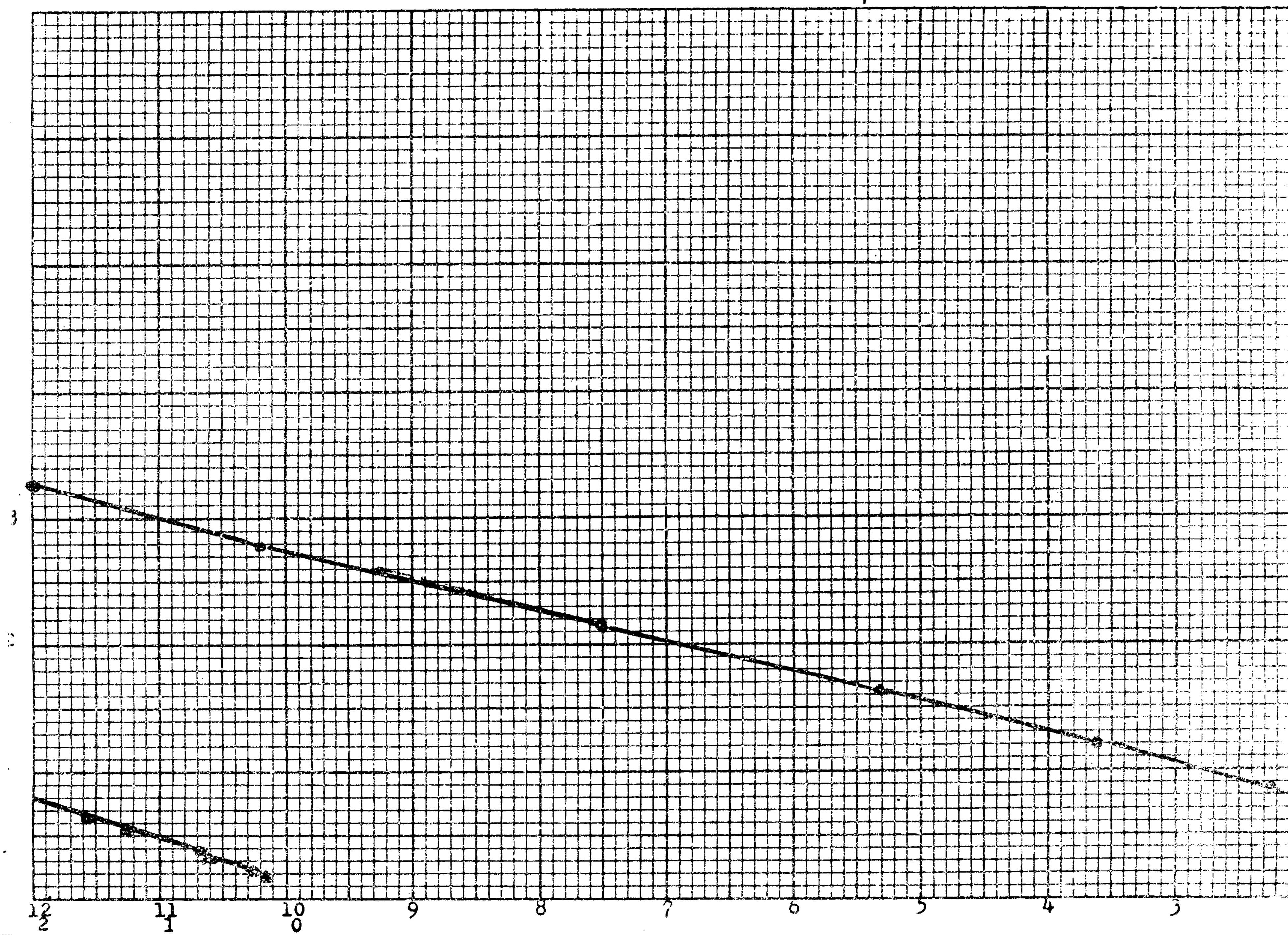
where the Γ's are constants for a given pitch angle. The doppler frequencies along the beams are related to these velocities by

$$f_{D_1}' = f_{D_2}' = \frac{2f'}{C'} \left[\Gamma_3 V_x' + \Gamma_4 V_y'\right]$$

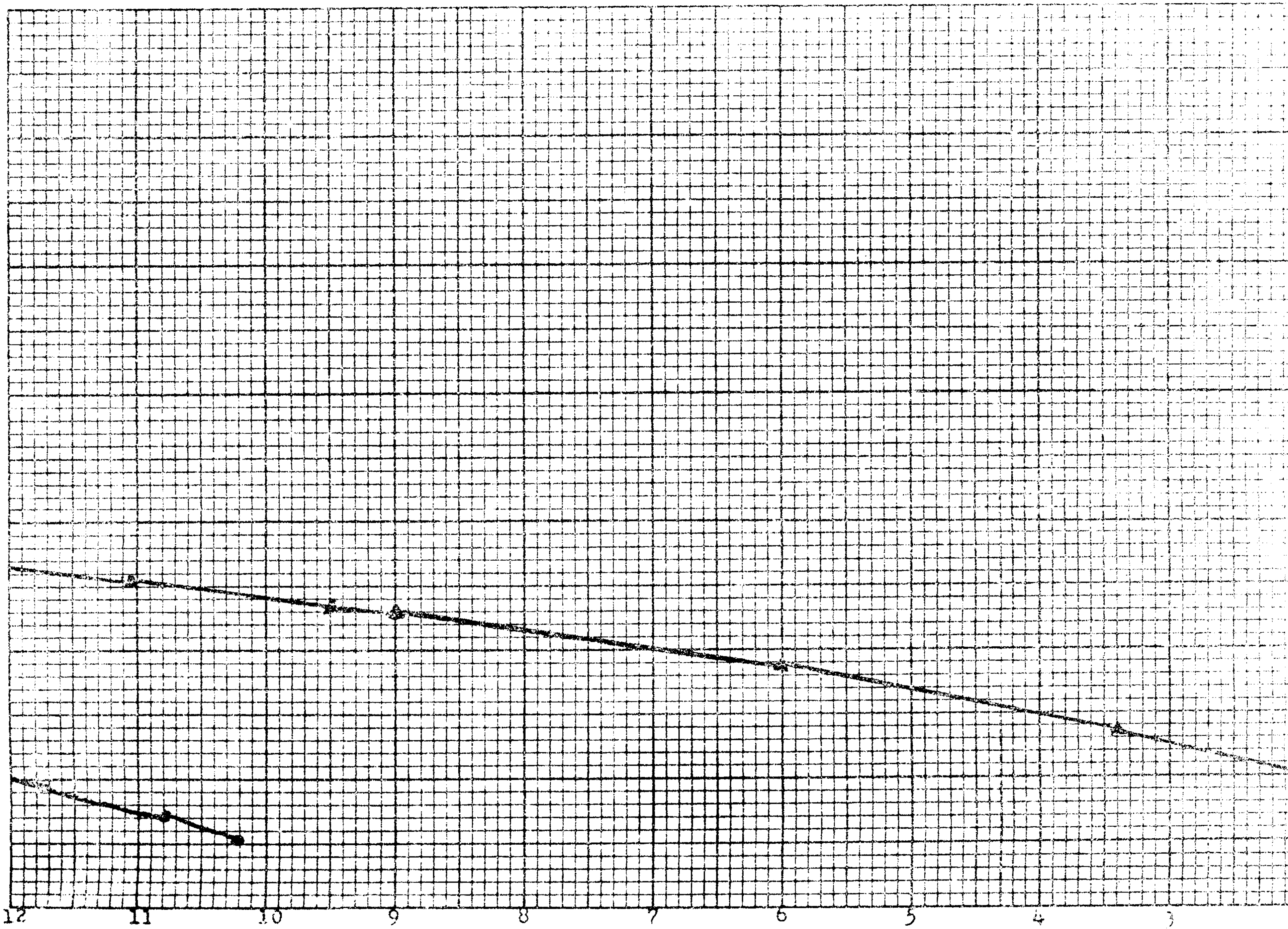
$$f_{D_3}' = \frac{2f'}{C'} \left[\Gamma_1 V_x' - \Gamma_2 V_y'\right]$$

Preliminary calculations indicate these frequencies will lie between 0 and 150 HZ for all points along the simulated trajectory.

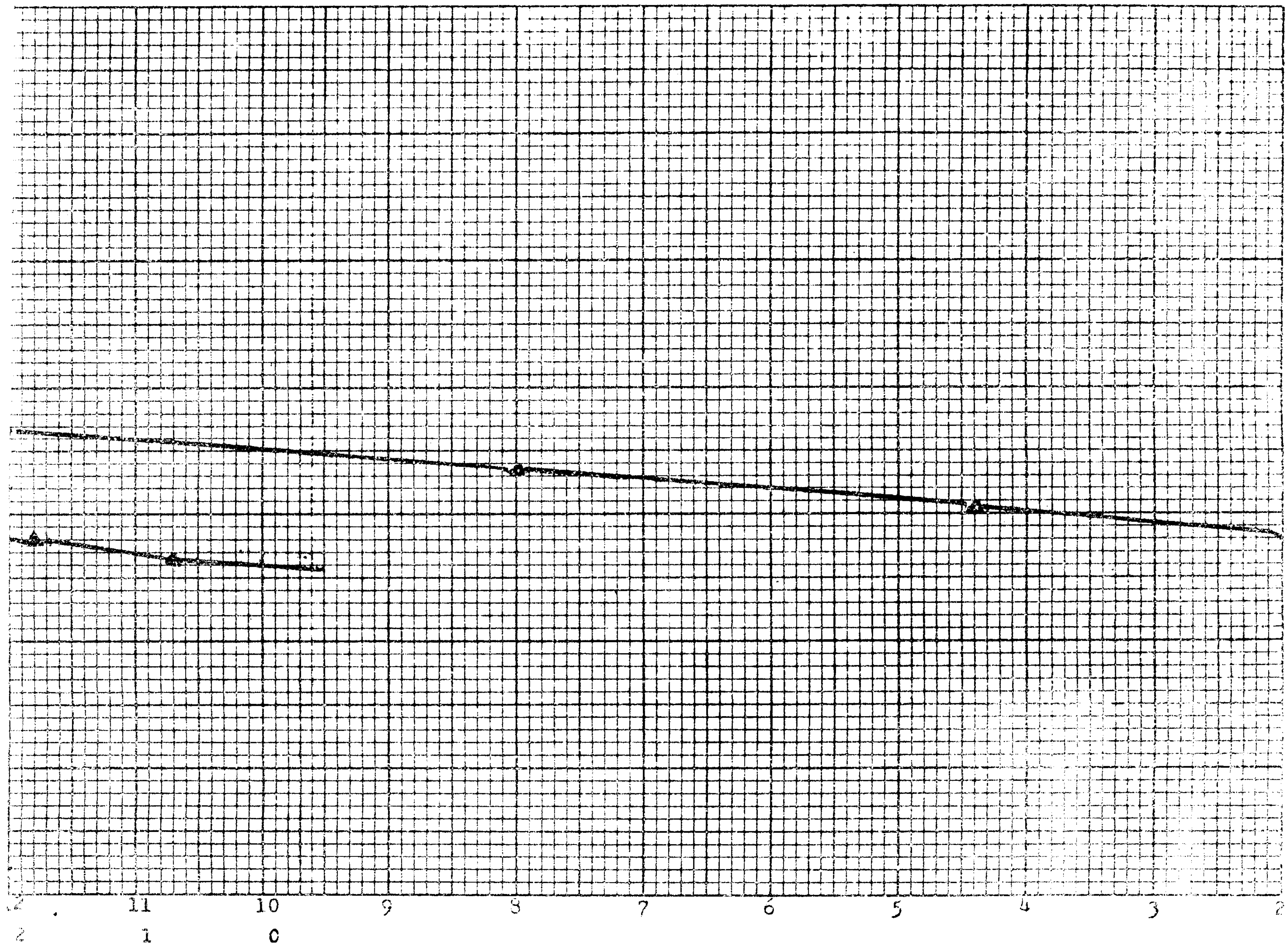
TRAJECTORY OVER PROBABILITY ELLIPSE $\gamma_{s_1} = 1080$



TRAJECTORY #1 OVER TARGET #2 $Y_L = 6850$

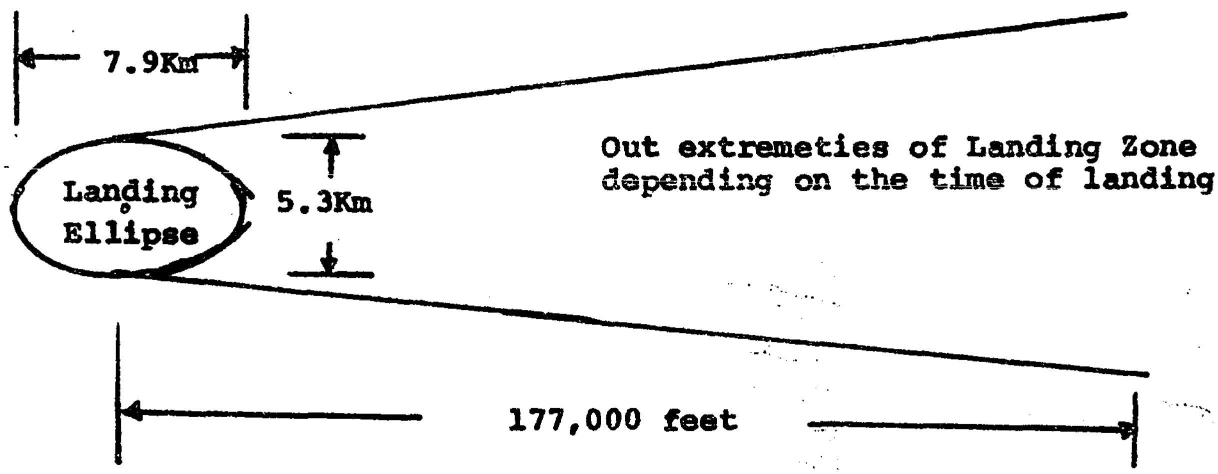


TRAJECTORY # OVER TARGET #2 $\gamma_{s_\perp} = 6850$



LUNAR SURFACE MODELING

The LEM radar beam covers a distance of 177,000 feet on the lunar surface during its final journey. It approaches from the east and is expected to land on a pre-selected probability ellipse with major and minor axes of 7.9 and 5.3 km respectively as shown below.



It is assumed that the vehicle is going to land near the center of the landing ellipse and that more detailed data is necessary for this area. Therefore, scale models are designed for the ellipses, while the rest of the approaching track is simulated at smaller scale.

The lunar surface roughness is assumed to be composed of a random component ξ_R and a more or less recurrent component ξ_ρ.

Random roughness ;

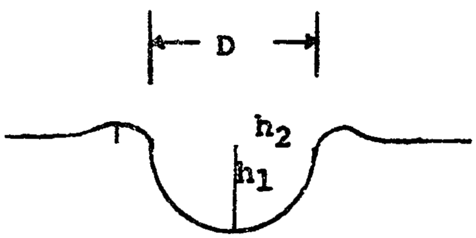
$\langle \xi_R \rangle = 0$

The criterion for roughness for vertical incidence is

$\frac{\sigma}{\lambda} = .125$ for vertical incidence [Hayre 1962]

The recurrent component of surface roughness ξ_ρ is made up of craters , crater rims, and hills as shown below by one typical segment of it

Crater



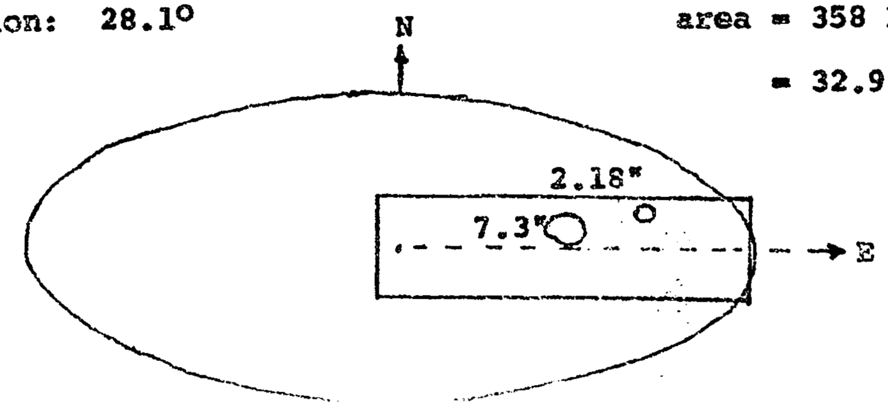
$D = a h_1 = b h_2$

where $\langle a \rangle \geq 3$ and $\langle b \rangle = 30$ $10\langle a \rangle$

Sun elevation: 28.1°

area = 358 K^2 ft^2

= 32.9 K^2 m^2



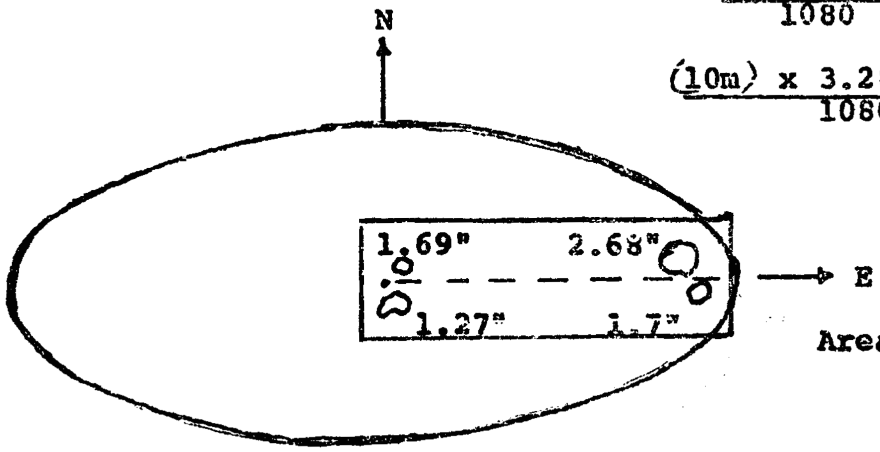
Site II P-8

Sun elevation: 27.8°

Scale: 1080:1

$$\frac{(KM) \times 3281}{1080} = 3.03 \text{ ft/Km}$$

$$\frac{(10m) \times 3.281 \times 12}{1080} = .363 \text{ in/10m}$$



Area = $358K^2 ft^2$

= $32.9K^2 m^2$

Significant Hazards

Depth	Diameter	Mean	h'	h_2	Number	Area	% Area
19m	51m		17m	1.7m	1		
19m	1.85"		.62"	.062"	1		
35m	95m		31.7m	3.17m	1		
	3.44"		1.14"	.114"			
47m	118m		39m	3.9m	1		
	4.25"		1.4"	.14"			
74m	200m		67m	67m	1		
	7.3"		2.43"	.243"			
Others							
	11.4m→22.8m	17.1	.12"→.275"	.012"→.0275"	11,632	$2.56K^2m^2$	7.8
	.41"→.825"	.62"					
	22.8m→34.2m	28.5	.275"→.41"	.0275"→.041"	610	$.423K^2$	1.[illegible]
	.825"→1.24"	1.03"					
	34.2m→45.6m	39.9	.41"→.55"	.041"→.055"	215	$.266K^2$	.86
	1.24"→1.66"	1.45"					

Site II P-11

Sun Elevation 28°

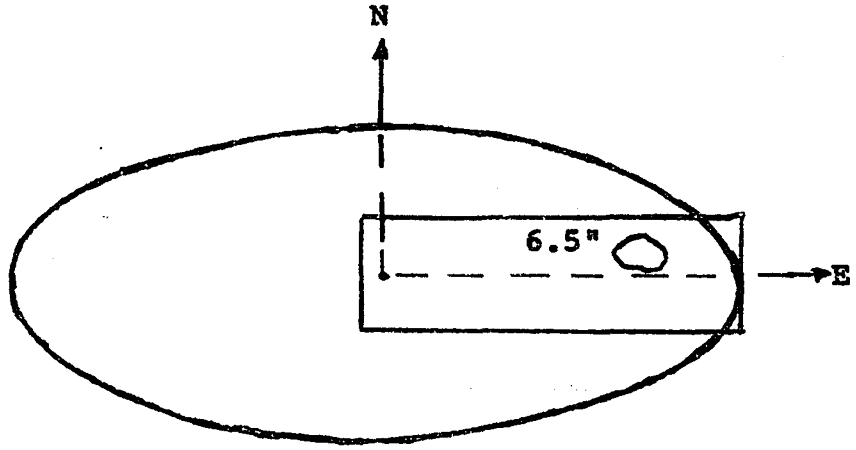
Area = $358K^2 ft^2$

= $32.9K^2 m^2$

Scale 1080:1

$$\frac{(KM) \times 3281}{1080} = 3.03 \text{ ft/Km}$$

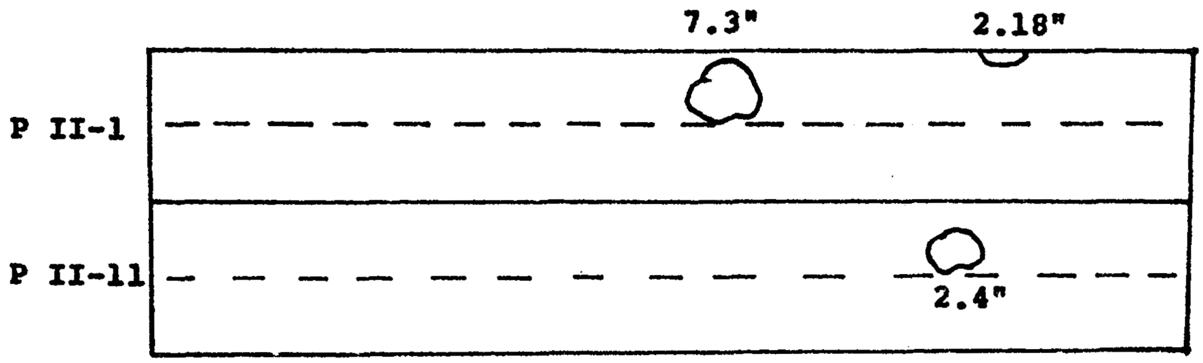
$$\frac{(10m) \times 3.281 \times 12}{1080} = .363 \text{ in/10m}$$



Significant Hazards

Depth	Diameter	Mean	h_1	h_2	Number	Area	% Area
66m 2.4"	180m 6.5"		60m 2.18"	6m .218"	1		
Others	11.4m→22.8m .41"→.825"	17.1m .62"	.12"→.275"	.012"→.0275"	8840	$2K^2m^2$	6.1%
	22.8m→34.2m .825"→1.24"	28.5m 1.03"	.275"→.41"	.0275"→.041"	324	$.21K^2$	.64%
	34.2m→45.6m 1.24"→1.66"	39.9m 1.45"	.41"→.55"	.041"→.055"	139	$.18K^2$	.55%

Further study of the elliptical landing zone and its modeling suggests that Sites P II-6 and P II-11 approach areas be modeled on separate portions on the same 4' x 12' frame without their respective features overlapping throughout the entire radar beam coverage.

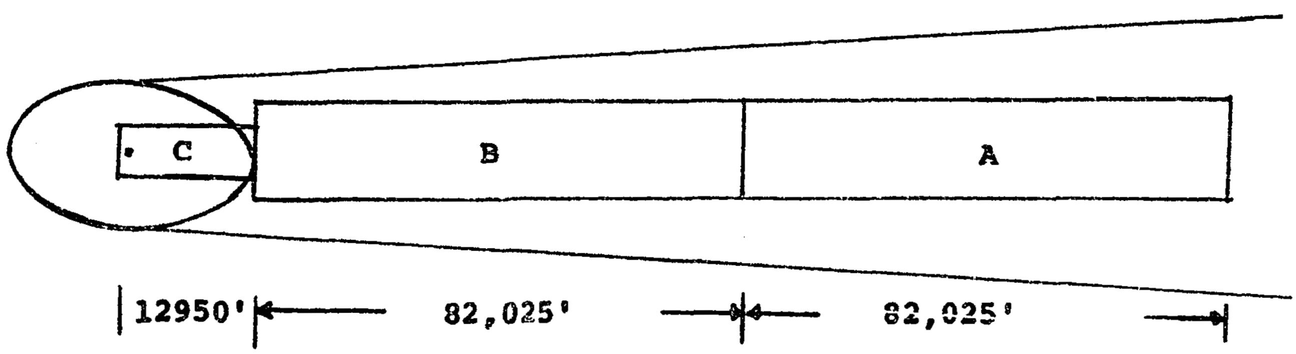


The significant hazards within the elliptical sites will be modeled using linear scale factor techniques whereas the other smaller craters with their size and location randomly distributed over the entire model plane will be modeled with similar distribution of protuberances in a random fashion.

Approaching Radar Track

The approach zones which extend approximately 164,050 feet are simulated by two sections, each 82,025 feet in length, and modeled by 4' x 12' surface each, as shown below.

Scale: 6850:1



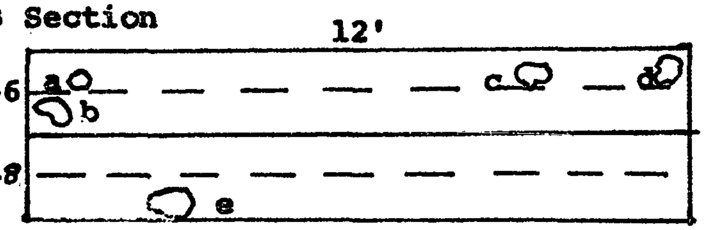
A close study of the medium resolution pictures of the three selected sites indicates that Sites P II-6 and P II-8 should be modeled on the same plane. Since the roughness of the sections A and B of these two sites are dotted sections by craters while site P II-11 is hilly. Therefore Site P II-11 has to be modeled separately.

A & B Section

Scale: 6850:1

P II-6

P II-8



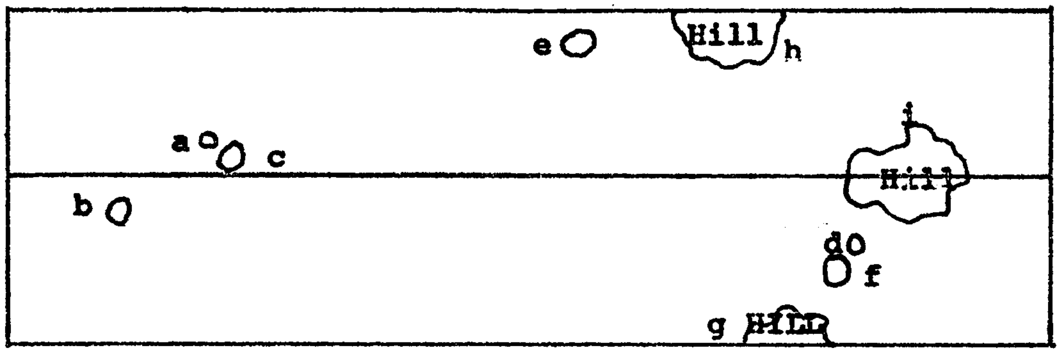
$$\frac{(KM) \times 3281}{6850} = .48 \text{ ft/Km}$$

$$\frac{(10m) \times 3.281 \times 12}{6850} = .057 \text{ in/10M}$$

P II-6 Hazards

	Depth	Diameter	h_1	h_2
A.	41m 235"	112m .64"	37m .21"	3.7m .021"
B.	54m .31"	148m .85"	49m .28"	4.9m .028"
C.	106m .61"	280m 1.6"	96.5m .55"	9.65m .055"
D.	138m .79"	375m 2.15"	125m .72"	12.5m .072"
P II-8 Hazards				
E.	105m .6"	285m 1.63"	95m .54"	9.5m .054"

B Section of P II-11



Site P II-11 Hazards

Scale 6850:1

.48 ft/Km
.057 in/10m

	Depth	Diameter	h_1	h_2
A.	47m .21"	128m .73"	42.5m .24"	4.25 .024"
B.	49m .28"	134m .77"	45m .26"	4.5m .026"
C.	69m .385"	188m 1.07"	62.5m .356"	6.25m .036"
D.	78m .45"	213m 1.22"	71m .4"	7.1m .04"
E.	94m .54"	256m 1.47"	85m .49"	8.5m .05"
F.	133m .76"	360m 2.06"	120m .69"	12m .07"

Hills

G.	261m	1.5"
H.	286m	1.64"
I.	320m	1.83"

SIGNIFICANT HAZARDS

Depth	Diameter	h_1	h_2	Number
24m .87"	65.5m 2.18"	21.7m .73"	2.17m .073"	1
74m 2.68"	200m 7.3"	67m 2.43"	6.7m .243"	1

OTHER CRATERS

Diameter	Mean	h_1	h_2	Number	Area	% Area
11.4m → 22.8m .41" → .825"	17.1m .62"	.12" → .275"	.012" → .0275"	5345	1.23K^2m^2	3.75%
22.8m → 34.2m .825" → 1.24"	28.5m 1.03"	.275" → .41"	.0275" → .041"	289	~2K^2m^2	.6%
34.2m → 45.6m 1.24" → 1.66"	39.9m 1.45"	.41" → .55"	.041" → .055"	92	.115K^2m^2	.35%

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